# How much information is required to well-constrain local estimates of future precipitation extremes?*

Summary: Much more than you think …

C. Li[1], X. Zhang[2], F.W. Zwiers[1], G. Li[2]
[1]PCIC, University of Victoria, [2]CDAS/ECCC, Toronto

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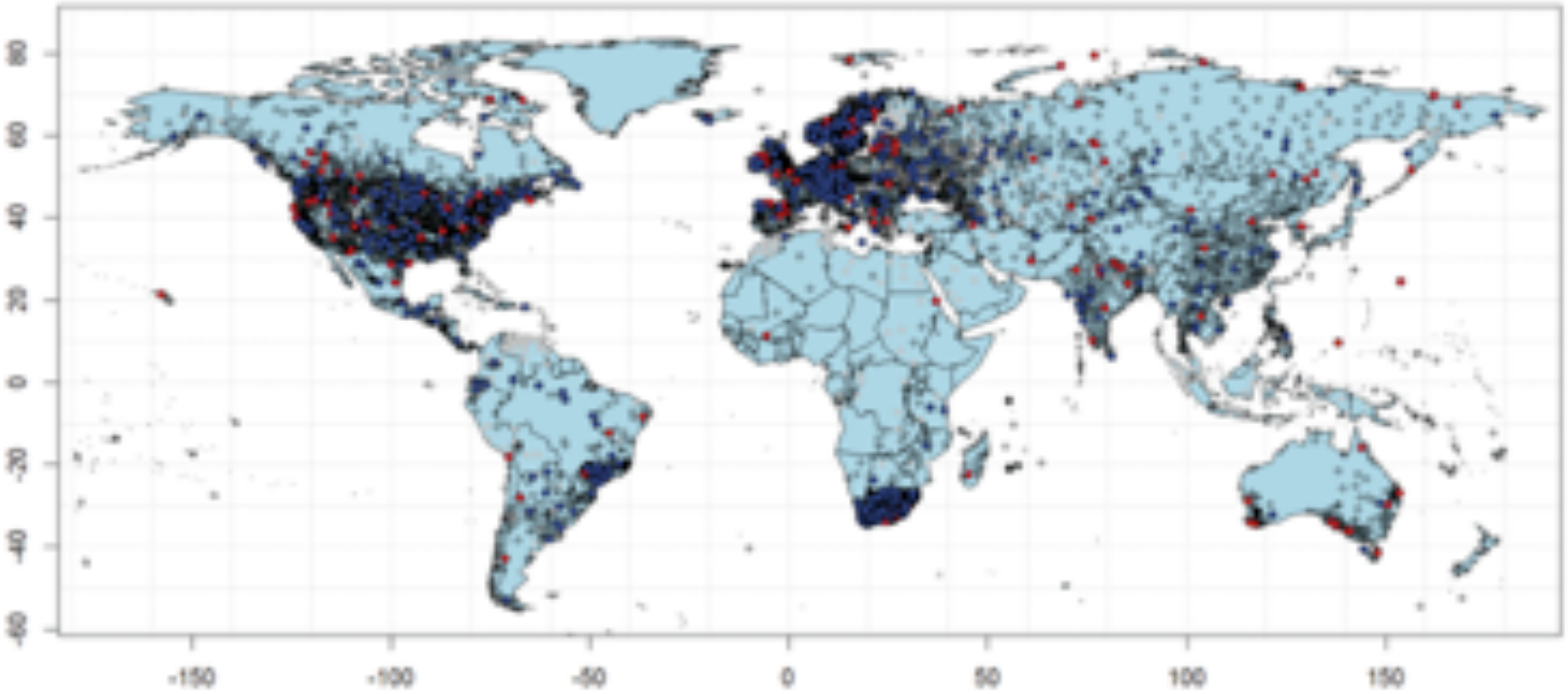
# Introduction

# Precipitation extremes

- Observational studies suggest intensification is occurring
- Expectation of intensification is supported by attribution of
  - global warming
  - atmospheric water vapour content increase
  - large scale changes in mean precipitation and ocean surface salinity
- Only a few D&A studies to date on extreme precipitation
  - detect human influence at the "global" scale
- Considerable challenges remain in understanding regional precipitation change (e.g., Sarojini et al., 2016)
- Local detection of change is very hard

# Is there an association between annual maximum 1-day precipitation and global mean temperature?




- 8376 stations with > 30 yrs data, median length 53 yrs
- Significant positive (10.0% of stations, expect 2.5%)
- Significant negative (2.2% of stations, expect 2.5%)
- Estimate of mean sensitivity over land is ~7%/K

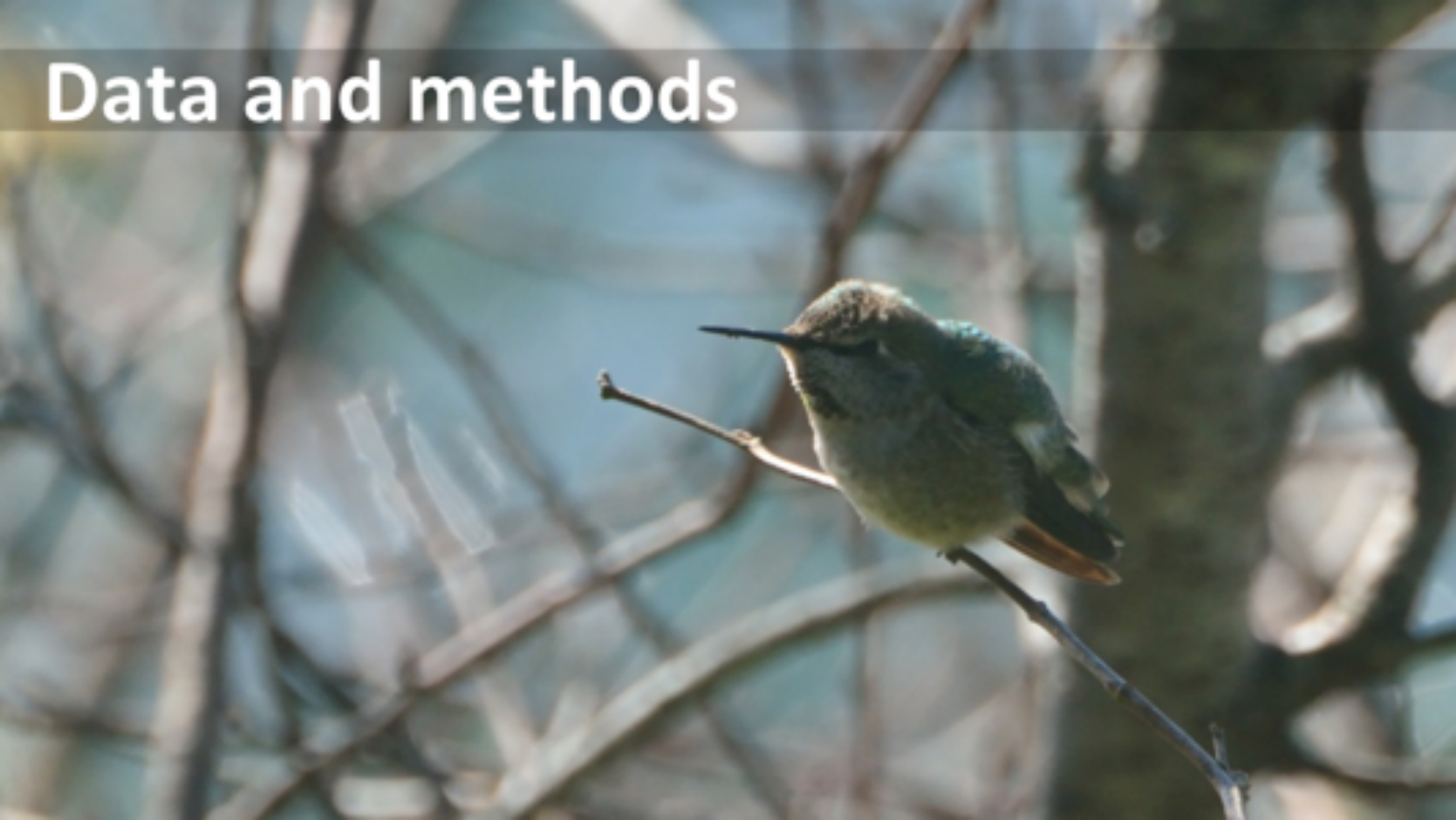
Westra et al (2013, Fig. 5); see also Barbero et al., 2017 for a similar study of US data

# Challenges

- Global evidence implies "stationarity is dead" (Milly et al, 2008), but local evidence of non-stationarity is weak
  - Makes the application of location-specific non-stationary extreme value models difficult
  - Similarly makes climate model selection for the purposes of projecting changes in engineering design values difficult
- Some guidance can be derived from broad thermodynamic arguments, eg., the Clausius-Clapeyron relation
- Circulation change, which is uncertain, is likely to be an important confounding factor

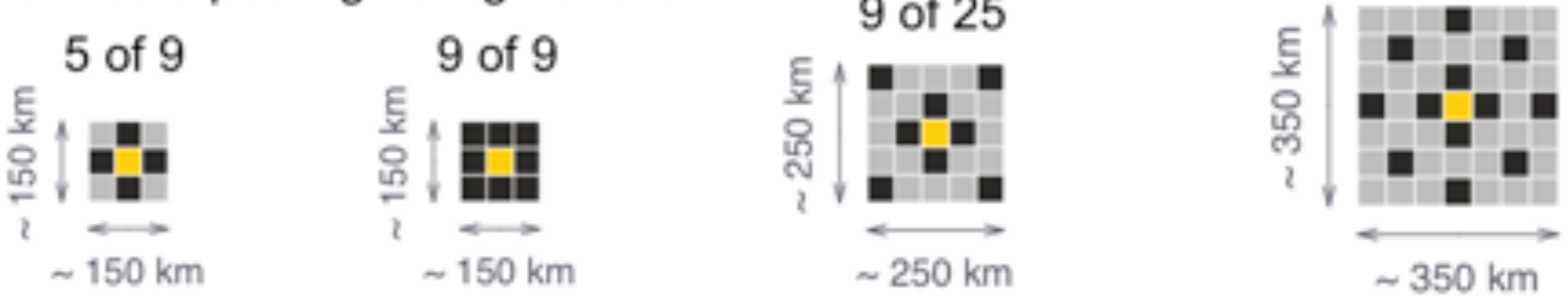
Nevertheless, can we make some headway by making intelligent use of temperature scaling?

# Data and methods



# Data and methods

- Large ensemble of North American regional climate simulations
  - 35 runs produced with CanRCM4 (50 km resolution) driven with CanESM2
  - 1951-2100, historical ALL forcing + RCP8.5
  - Analyze simulated annual precipitation extremes for 1, 6, 12 and 24-hour accumulation periods
- Use non-stationary GEV distributions together with the "index-flood" regional frequency analysis approach
  - Non-stationarity is accounted for with a temperature covariate
  - Four data pooling configurations



# GEV parameterization

- Let $Y_{s,t}$ be the annual maximum at location $s$ and year $t$

$$Y_{s,t} \to_D GEV(\mu_{s,t}, \sigma_{s,t}, \xi_{s,t}) = \begin{cases} \exp\left\{-\left[1 + \frac{\xi_{s,t}(y - \mu_{s,t})}{\sigma_{s,t}}\right]^{-1/\xi_{s,t}}\right\}, \xi_{s,t} \neq 0 \\ \exp\left\{-\exp\left[-\frac{y - \mu_{s,t}}{\sigma_{s,t}}\right]\right\}, \xi_{s,t} = 0 \end{cases}$$

- Note that $Y_{s,t}/\mu_{s,t} \sim GEV(1, \gamma_{s,t}, \xi_{s,t})$ where $\gamma_{s,t} = \sigma_{s,t}/\mu_{s,t}$

- Assume there are homogeneous regions $U$ such that

$$\gamma_{s,t} = \gamma_t \text{ and } \xi_{s,t} = \xi_t \text{ for all } s \in U$$

- That is, assume that $Y_{s,t} \sim GEV(\mu_{s,t}, \mu_{s,t}\gamma_t, \xi_t)$ for all $s \in U$

# GEV parameterization

- Second, assume that variation of parameters in time has the form

  $\mu_{s,t} = \tilde{\mu}_s \exp[\beta T_t']$

  $\gamma_t \ = \gamma \quad (\rightarrow \sigma_{s,t} = \gamma\, \tilde{\mu}_s \exp[\beta T_t'])$, and

  $\xi_t \ = \xi$

  where $T_t'$ is the global mean temperature anomaly

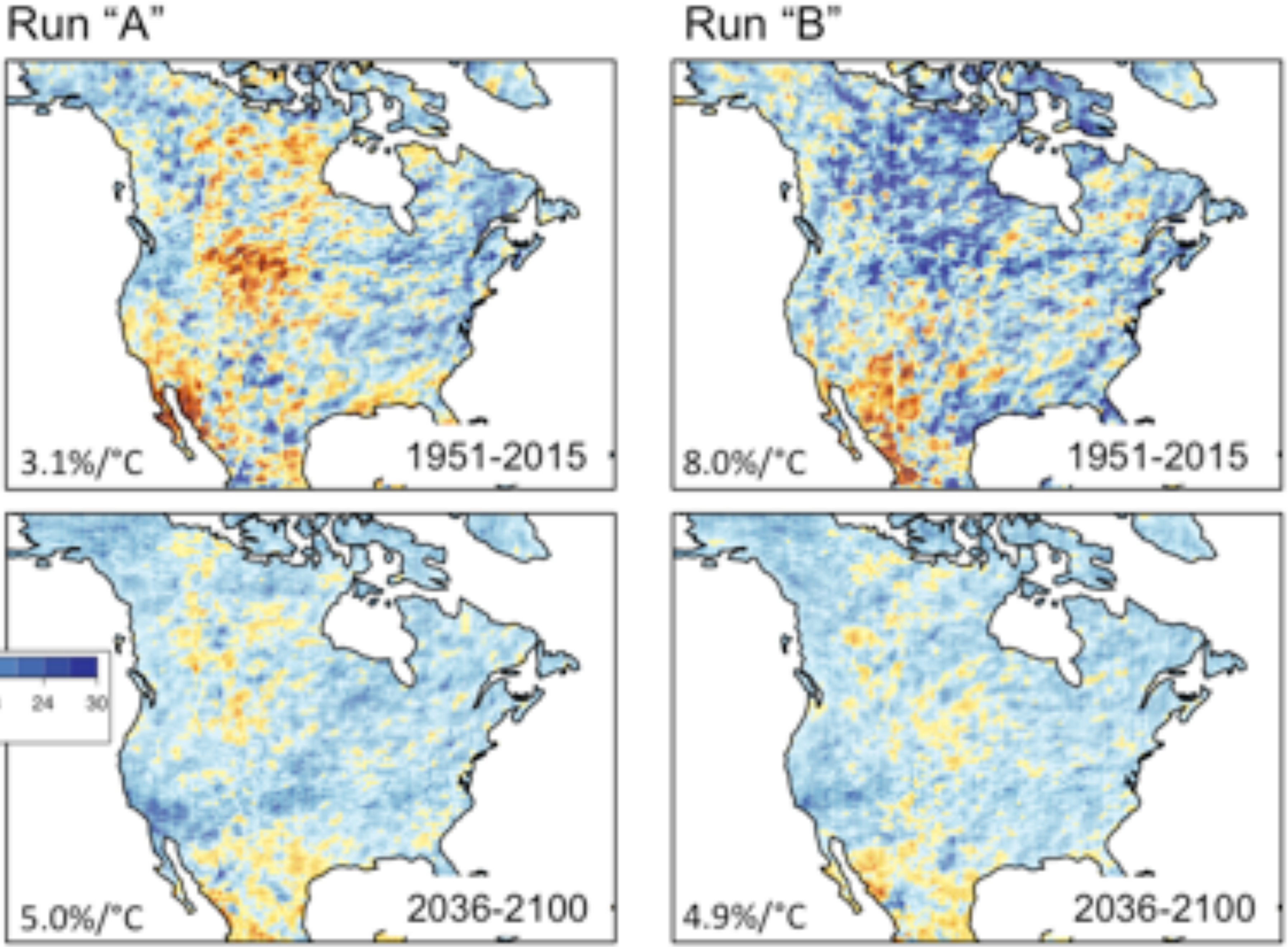
➔At each location, fit $Y_{s,t} \sim GEV(\tilde{\mu}_s \exp[\beta T_t'], \gamma\, \tilde{\mu}_s \exp[\beta T_t'], \xi)$ where

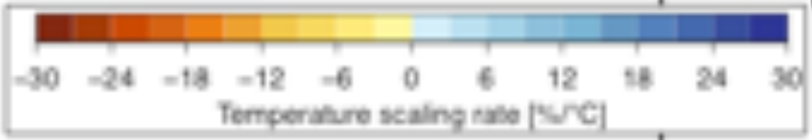
- $\tilde{\mu}_s$ is estimated at site, and
- $\beta$, $\gamma$ and $\xi$ are estimated from data pooled over a region $U$ centered on that location

✻This parameterization yields exponential scaling of quantiles with temperature of the form $(1 + r)^{\Delta T'}$ where $r = \exp[\beta] - 1$


Is at site analysis
sufficient?

Temperature scaling of annual maximum 12-hour precipitation estimated from 65-year periods from single CanRCM4 runs (at site)



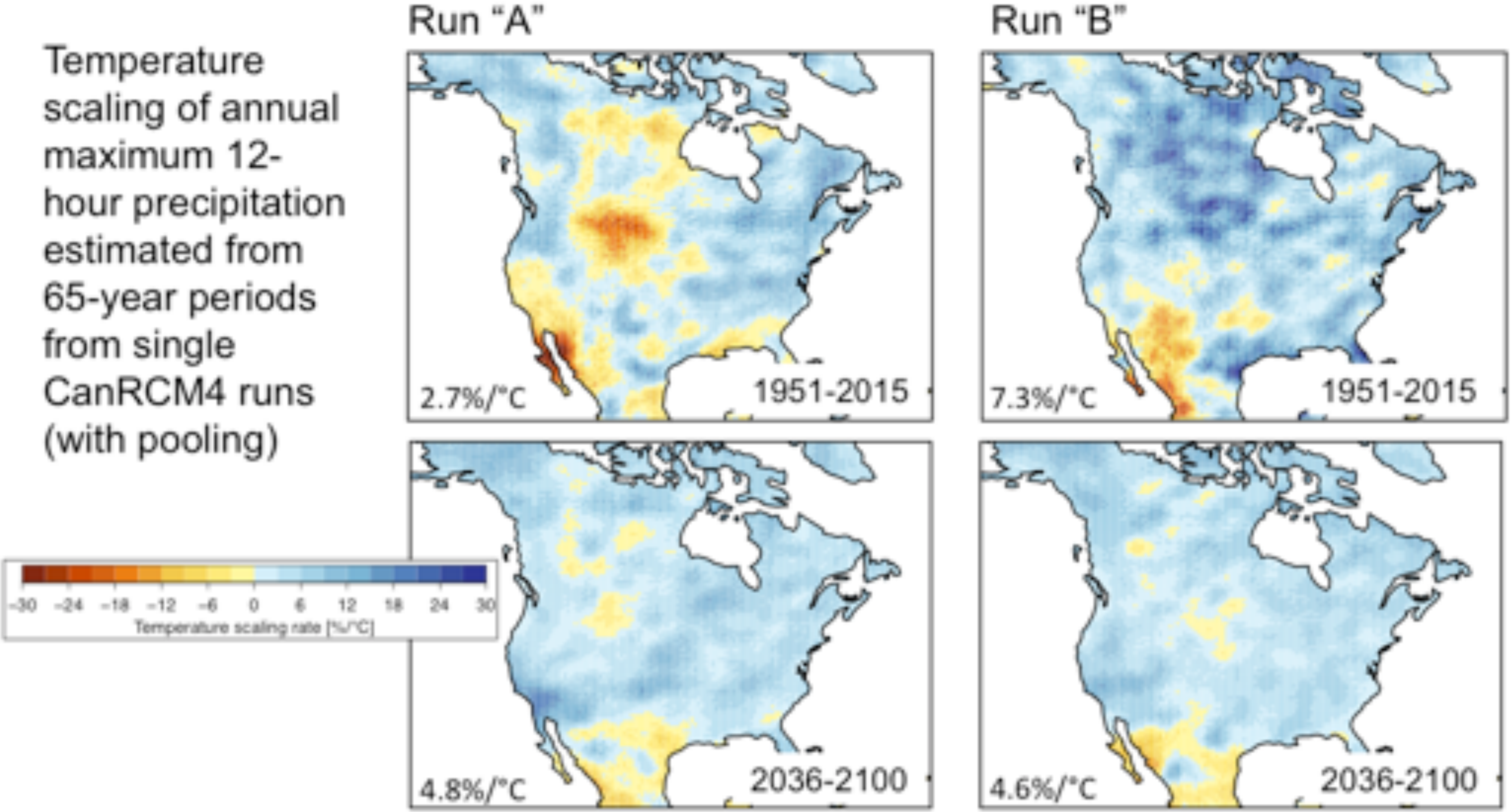



## Is at site analysis sufficient?

No. At site analysis of single 65-year records is insufficient to identify temperature scaling relationships (or more generally, is insufficient to reliably quantify non-stationary behaviour), even during periods with strong external forcing and response.


Does regional data pooling help?

Temperature scaling of annual maximum 12-hour precipitation estimated from 65-year periods from single CanRCM4 runs (with pooling)



## Does regional data pooling help?

Not a lot. RFA of single 65-year records is still insufficient to robustly identify temperature scaling relationships, but …
… it may help in identifying large scale features associated with individual realizations of low frequency teleconnected variability.

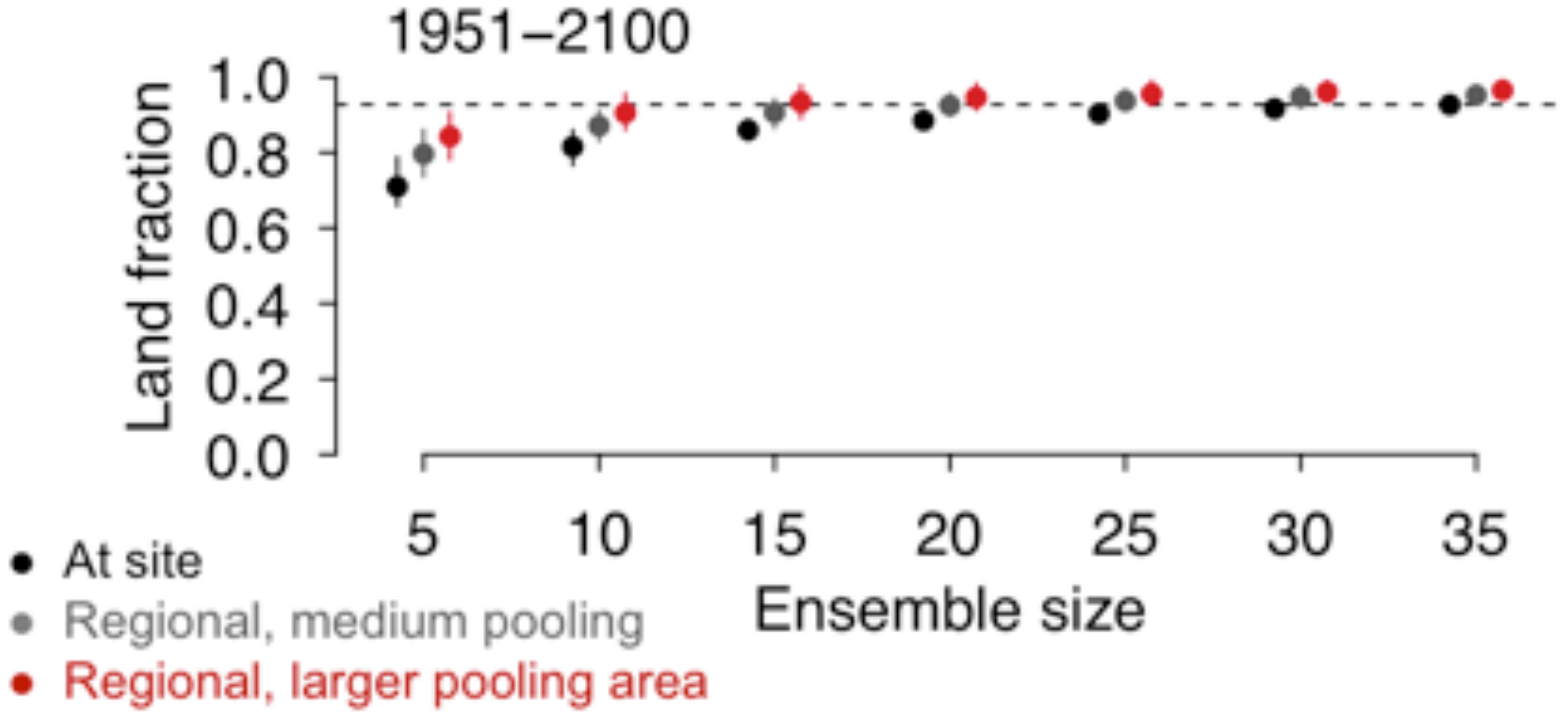
# If single, 65-year records are insufficient, how much data is required?

Measure scaling strength by $SRSE = \frac{\bar{r}}{s_r/\sqrt{n}}$

| | |
|---|---|
| Un-constrainable | $\lvert SRSE \rvert < 2$ |
| Constrainable | $2 \leq \lvert SRSE \rvert < 5$ |
| Robustly Constrainable* | $5 \leq \lvert SRSE \rvert$ |

* the 95% CI for $\bar{r}$ is narrower than $\bar{r}\pm0.5\bar{r}$

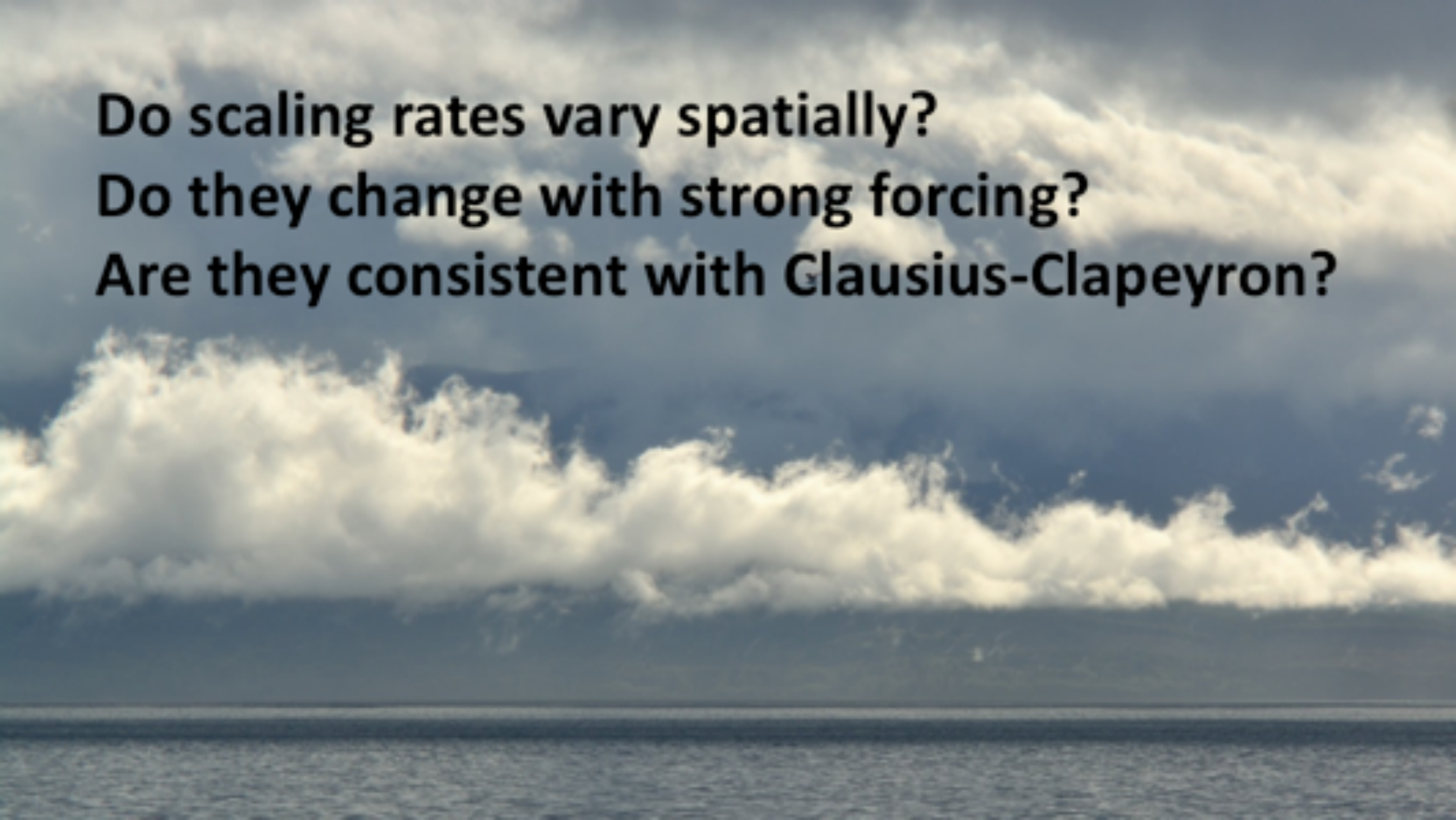
# Fraction of North America with robustly constrained temperature scaling estimates (annual max 12-hour precip)



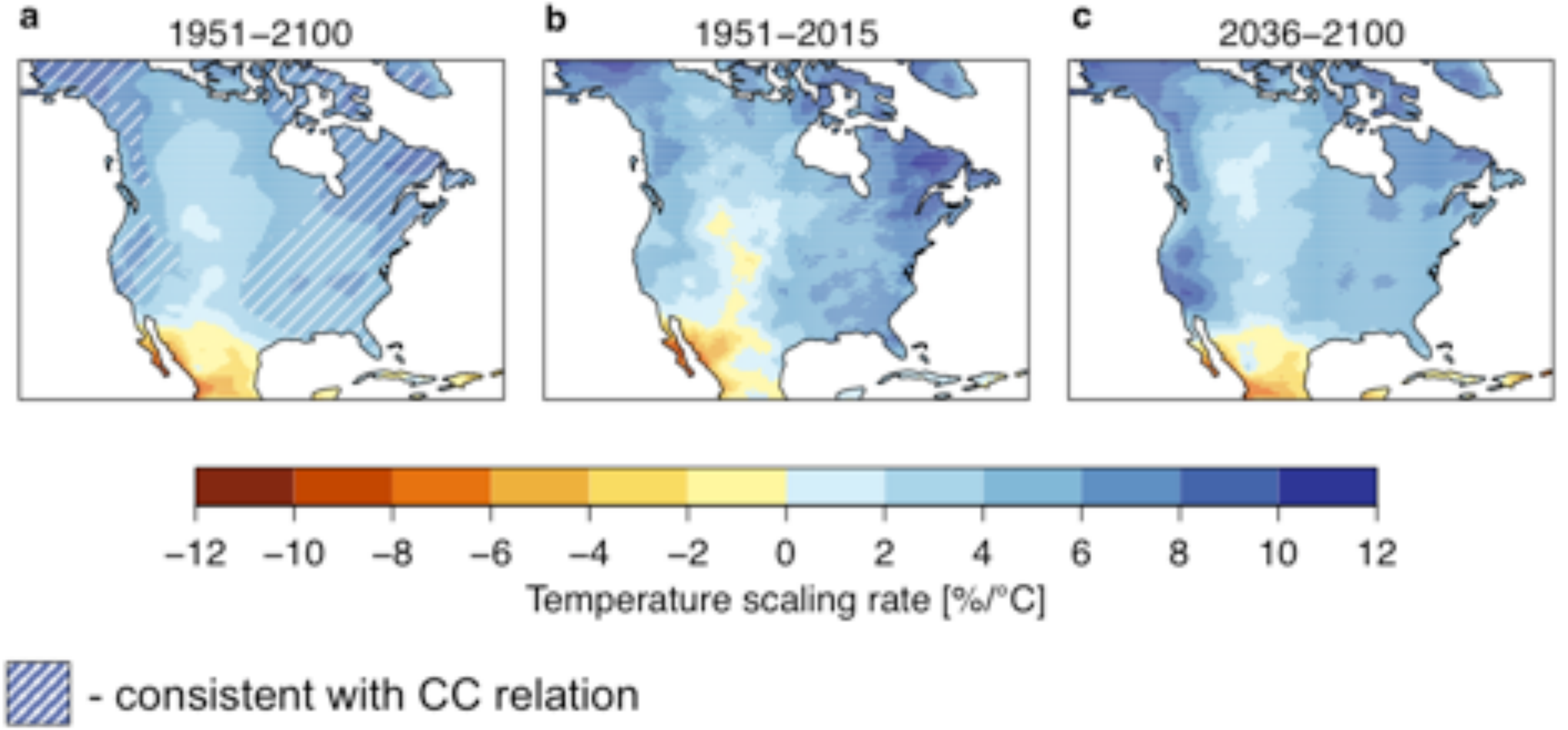
## If single, 65-year records are insufficient, how much data is required?

## Depends on pooling, record length, and signal strength …

- 35 realizations of a 65-year historical record is insufficient, even with aggressive data pooling
- 20 realizations of a future 65-year period is better
- 10-15 realizations of full 150-year period that includes a strong signal provides robust constraints


Do scaling rates vary spatially?
Do they change with strong forcing?
Are they consistent with Clausius-Clapeyron?

# Ensemble mean temperature scaling rate for annual maximum 12-hour precipitation based on 35 simulations



Do scaling rates vary spatially?

- yes, lower in the interior of the continent, negative at southern edge of the domain

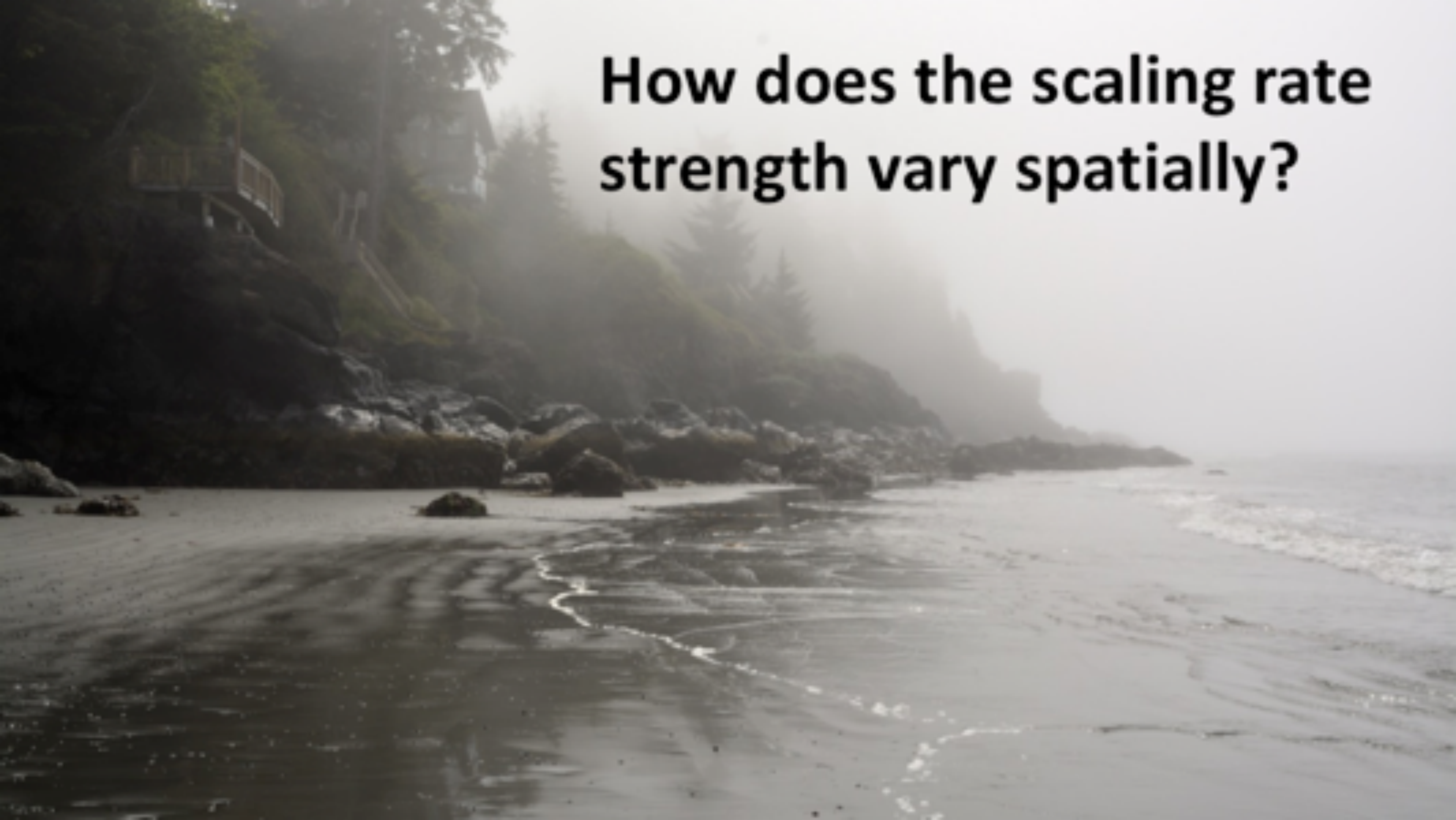
Do they change with strong forcing?

- no, they appear to be roughly consistent between 1951-2015 and 2035-2100, except for the south

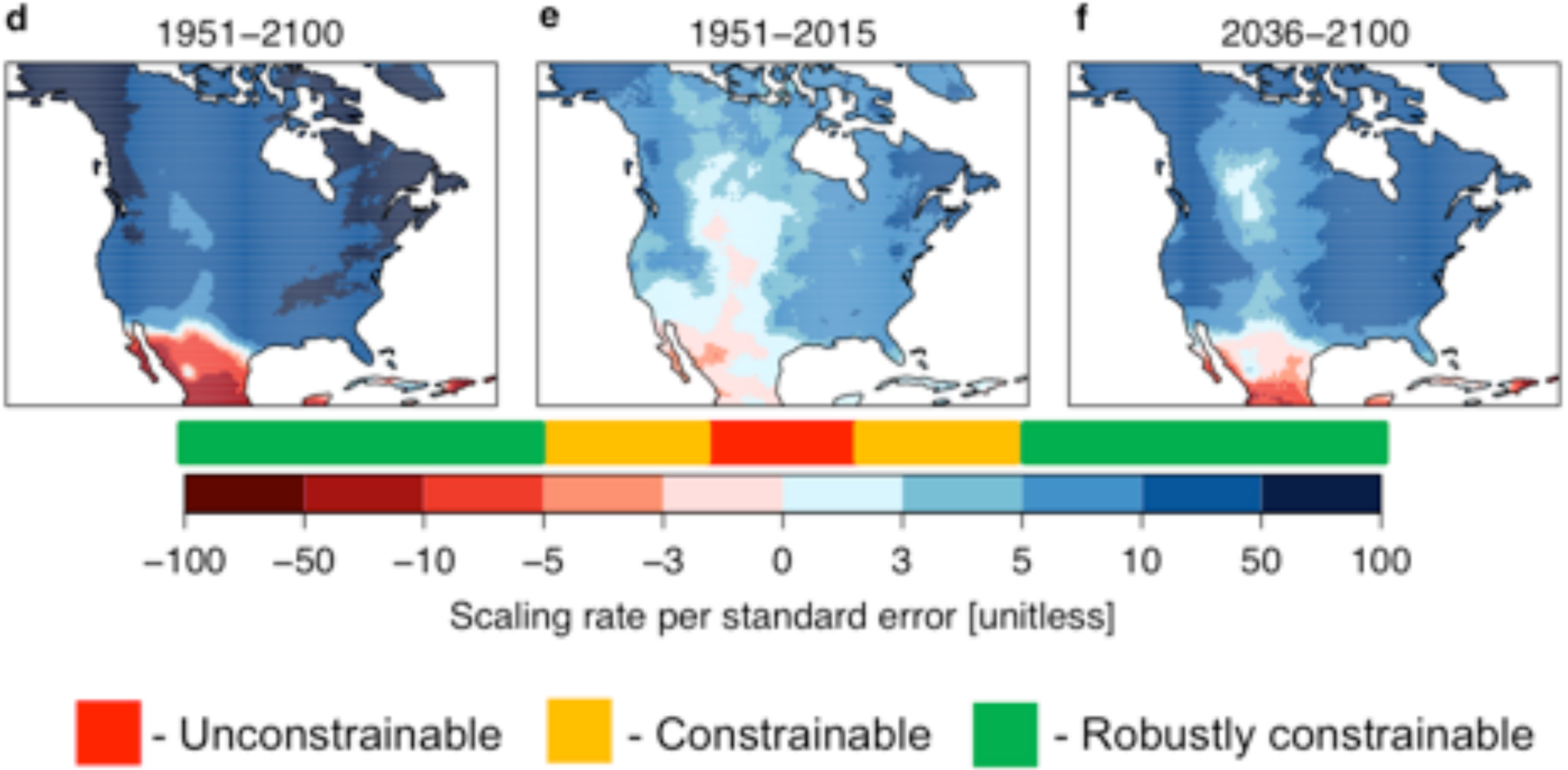
Are they consistent with Clausius-Clapeyron?

- not in the interior of the continent or the south

# How does the scaling rate strength vary spatially?



# Strength of temperature scaling for annual maximum 12-hour precipitation based on 35 simulations



How does scaling rate strength vary spatially?

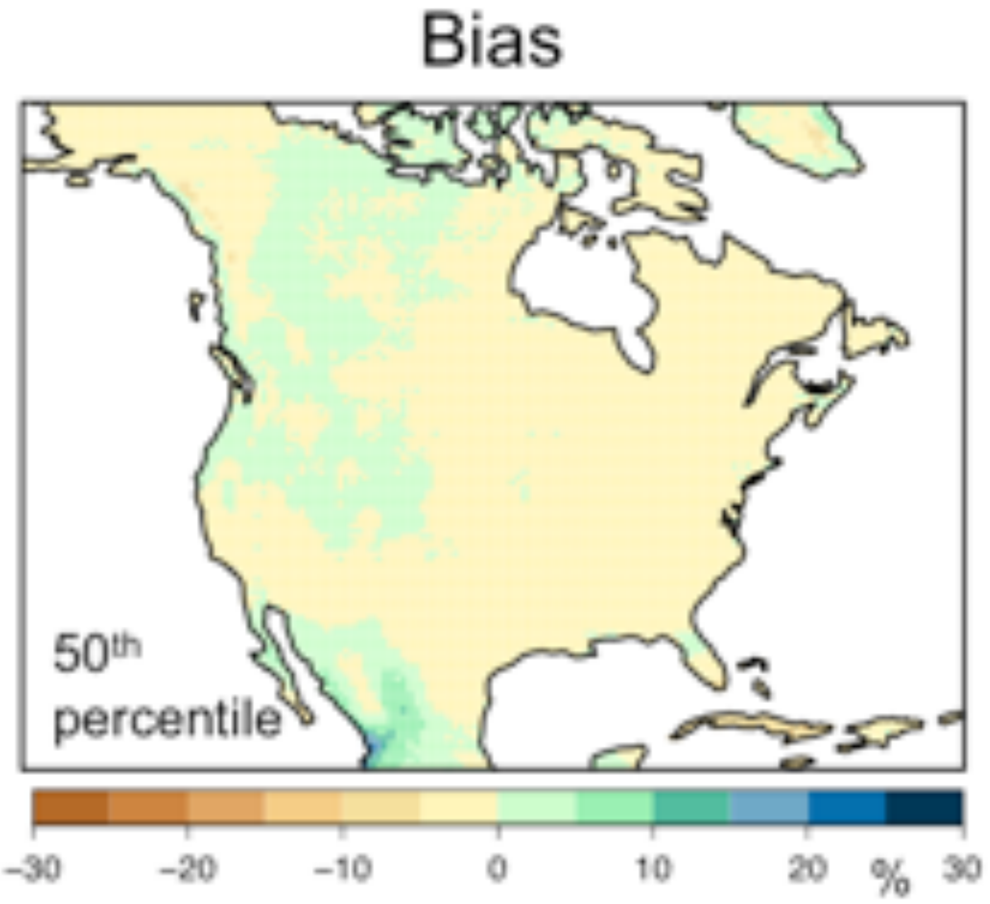
Rates are *constrainable* or *robustly constrainable* over most of the continent when using full 150-year simulations

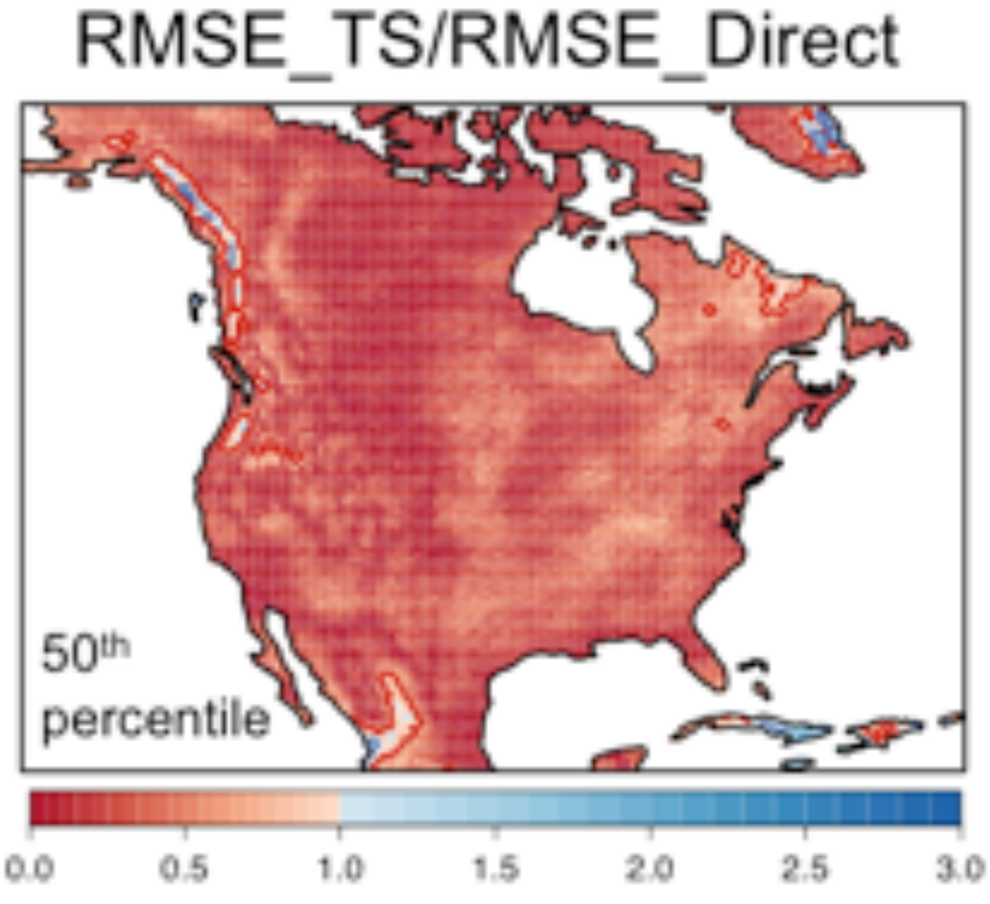
Most difficult to constrain in the high-elevation interior when restricting data to 1951-2015

# How useful is temperature scaling?

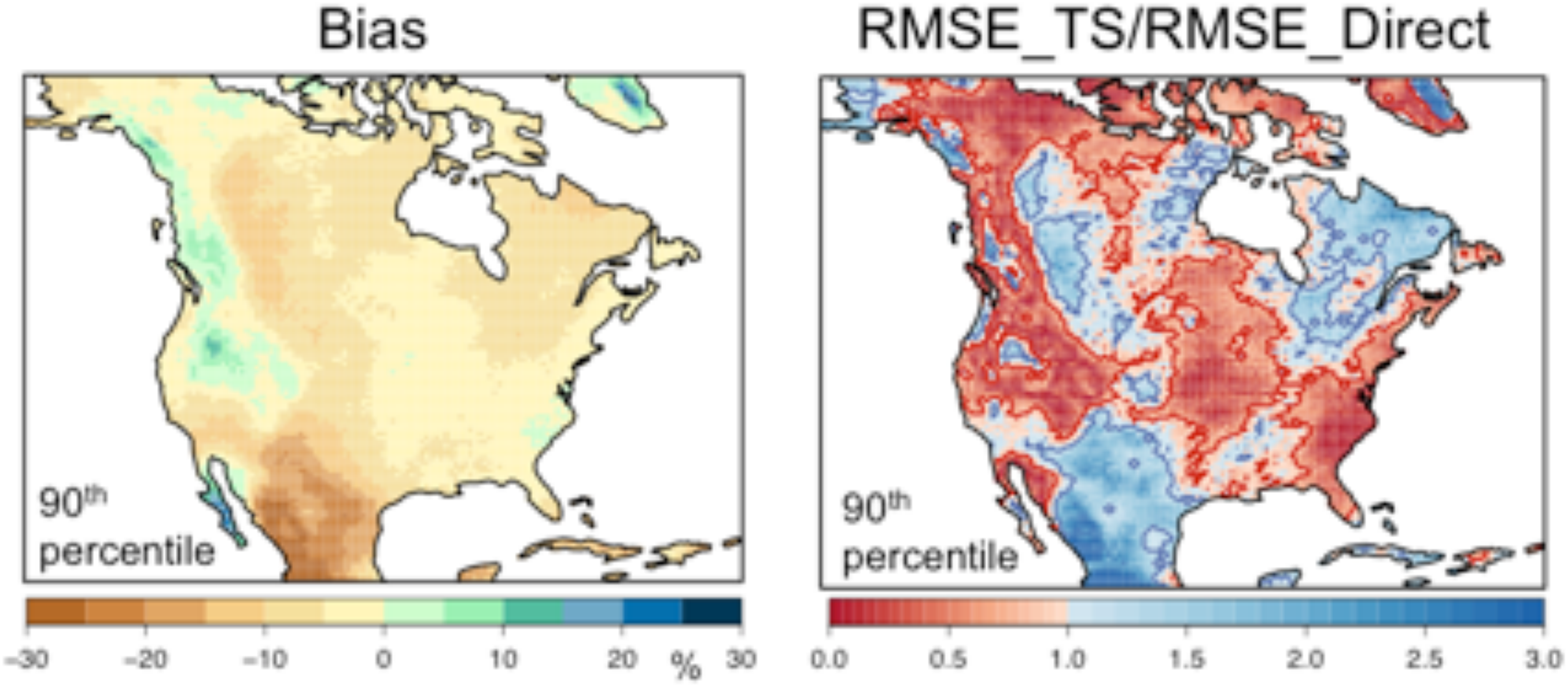
Compared bias and RMSE of direct estimates of quantiles of extremes from single simulations with corresponding temperature scaling constrained estimates of quantiles

# Temperature scaling performance relative to direct estimation for projection of change in annual maximum 12-hour precipitation during 2071-2100 versus1951-2015



# Temperature scaling performance relative to direct estimation for projection of change in annual maximum 12-hour precipitation during 2071-2100 versus1951-2015



# How useful is temperature scaling?

Provides a substantial advantage with little cost in terms of bias for moderate extremes (e.g., 2-year events)

Problems become apparent deeper in the tails, particularly as warming progresses, suggesting that our GEV parameterization (which builds in exponential scaling) may be too restrictive.

# Conclusions and Discussion

- Stationarity is dead, but …
- Non-stationarity is almost impossible to quantify robustly in records that are the length of, and have external influences the strength of, our observational record
- Temperature scaling not a panacea, but may be able to help constrain projected changes in extremes with relatively modest sizes of initial conditions ensembles
- Raises some troubling questions about current practice amongst practitioners and about the costs of ensemble experiments that will be needed to make robust projections with models that represent precipitation with greater fidelity
- Many caveats (eg., we have used a single conventionally parameterized regional climate model, etc)


Questions?
https://www.pacificclimate.org/